Dual Coolant Blankets and Helium Cooled Divertor Targets

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Characteristics of the Dual Coolant Lead Lithium (DCLL) Breeding Blanket

- Helium cooled First Wall and blanket structure

- Self cooled lead lithium breeding zone

- SiC flow channel inserts serving as electrical and thermal insulator

Key issues determining the performance of a power plant equipped with DCLL blankets

- Degree of thermal insulation between flowing LM and steel structure
- Maximum allowable interface temp. steel/lead lithium
- Maximum allowable temperature of FW/blanket structure
- Fraction of the total thermal power removed with the LM

➔ Achievable lead-lithium exit temperature

- Helium cooling conditions (pressure, flow rate, inlet/outlet temperature) required to remove FW surface heat flux and to meet the temperature criteria above
- Required pumping power for the helium coolant

➔ Achievable thermal efficiency in the power conversion system

Crucial areas for the DCLL blanket development

A) Flow channel inserts

B) MHD heat transfer including impact of natural convection

C) Fabrication of FW/blanket structure including ODS-plating at the FW

D) Blanket integration including manifolding, connection to coolant access pipes, mechanical attachment

Requirements on Flow channel inserts

a) Sufficiently low electrical conductivity

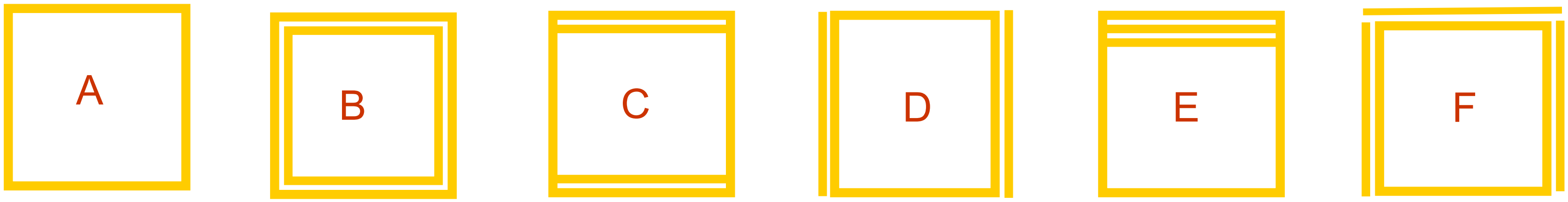
   Sigma < 20 S/m

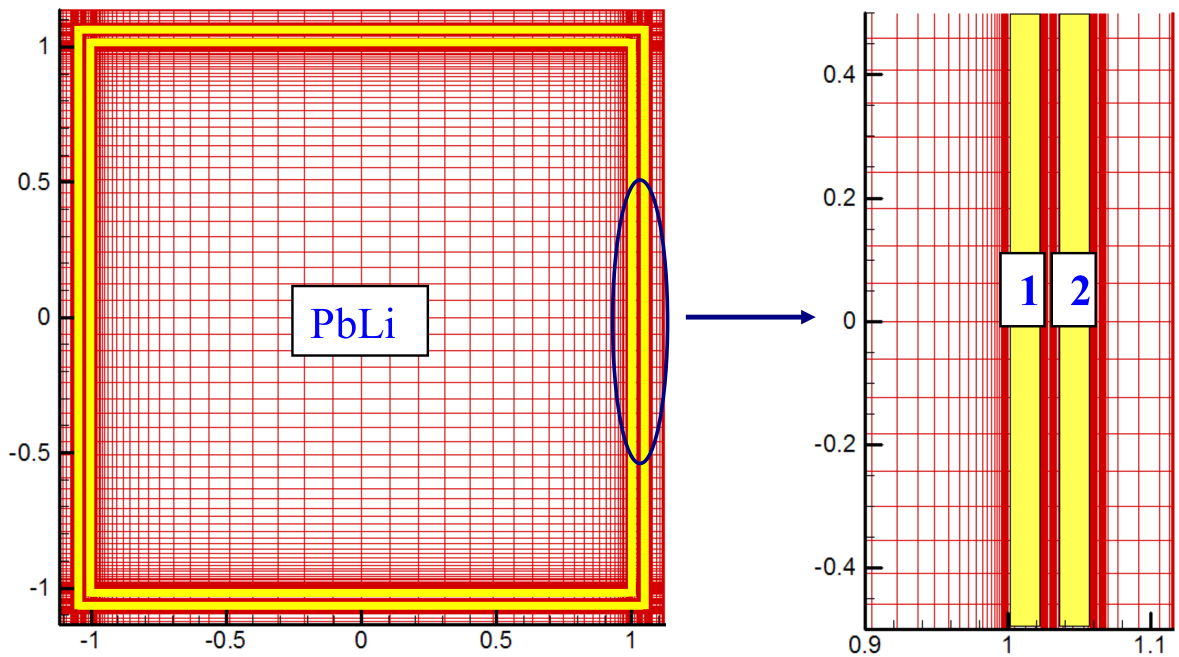
b) Low thermal conductivity k < 2 W/(m*K)

c) Surfaces sealed to avoid “soaking” of LM

d) Sufficient strength to survive thermal stresses

Analysis for “nested” FCI





NESTED (2-layer) FCI

DEMO (current design)

Front duct: 2a=207 mm;
2b=207 mm
FCI 1: 2.5 mm
Gap 1: 1 mm
FCI 2: 2.5 mm
Gap 2: 1 mm

σ_{SiC}=20 S/m
k_{SiC}=1 W/m-K

Various “nested” FCI options can be implemented. Here, Option B is considered.

E)

MHD heat transfer including impact of buoyant flow

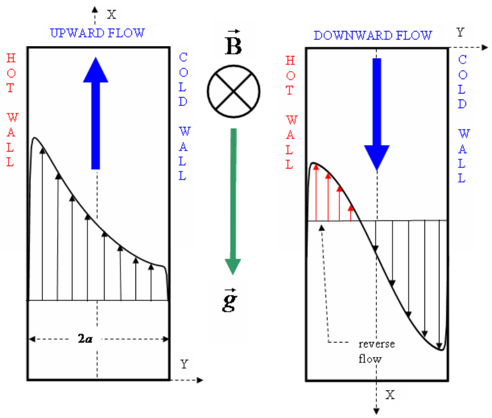
Analysis of buoyant flows

Motivation:

- In both ITER and DEMO, buoyant flows can be stronger than the forced flow. Buoyant flows will affect: heat losses, FCI ΔT, and the interface temperature.
- In the case where the forced flow is downwards, a “reverse” flow can appear at the “hot” wall. This may result in excessive local temperature increase in the PbLi.

Goals:

- To characterize velocity and temperature distributions in the poloidal ducts for two forced flow directions: upwards and downwards.
- To find conditions when the reverse flow appears (for downward flows).
- To apply the new theory to the poloidal flows in ITER and DEMO.



Parameter	ITER	DEMO IB	DEMO OB
Ha	6500	12,000	30,000
Re	30,000	60,000	40,000
Gr	7.0×10^{9}	3.5×10^{12}	2.0×10^{12}

Helium Cooled Divertor Targets

Why helium cooling and not water or liquid metal?

- **Cooling with (cold) water would not allow to use the divertor heat (10-15 % of total thermal power) in the power conversion system, copper heat sink as in ITER not possible for the large neutron fluence of a power plant,**

- **Liquid metal cooling would be limited to ~ 5 MW/m^2 surface heat flux (plasma physics requires at least 10 MW/m^2)**

Crucial issues of helium cooled divertor targets

- ***Exceptional high heat flux requires:***
  a) Structural material with high thermal conductivity (close to 1 W/(m*K)
  b) Heat transfer coefficient helium-wall at least 30,000 $W/(m^2*K)$

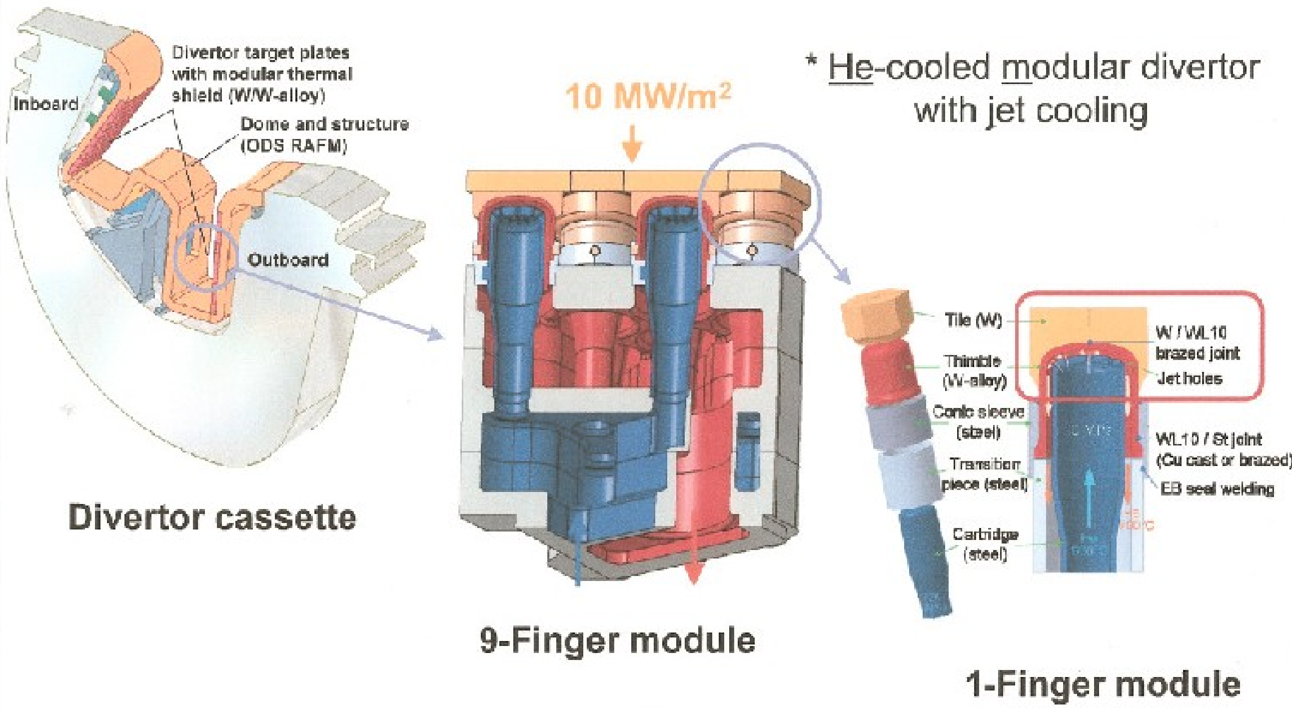
- ***Structural material required with a sufficiently large temperature window:***
  a) Minimum temperature above embrittlement limit
  b) Maximum temperature below recrystallization limit

- ***Thermal stresses and target deformation in an allowable range:***
  a) High heat flux causes large temperature gradient in the target (100 K/mm)
  -> large temperature differences across target plate
  b) Thermal stresses and deformations caused by these large temperature differences depend on the size of target and the kind of mechanical support : Alternatives are large plates, T-tube, or small modules

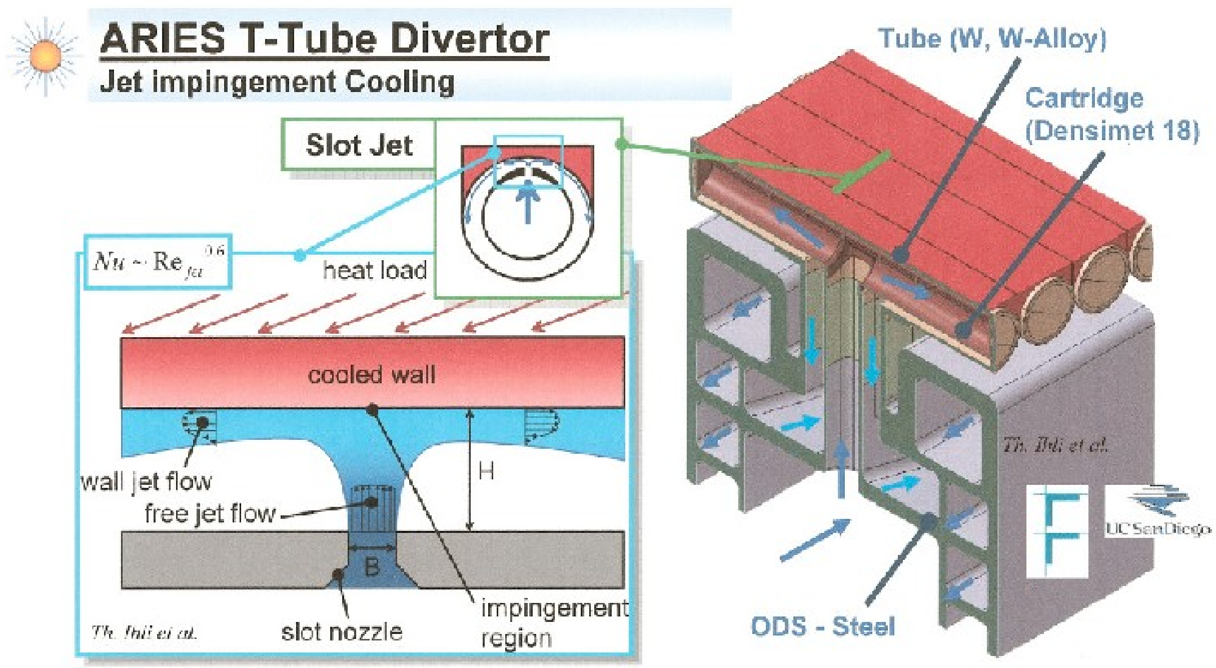
- ***Reliability of the divertor target is a big feasibility issue of the power plant***

The Reference Design HEMJ* (PPCS-B, -AB, -C), for 10 MW/m2

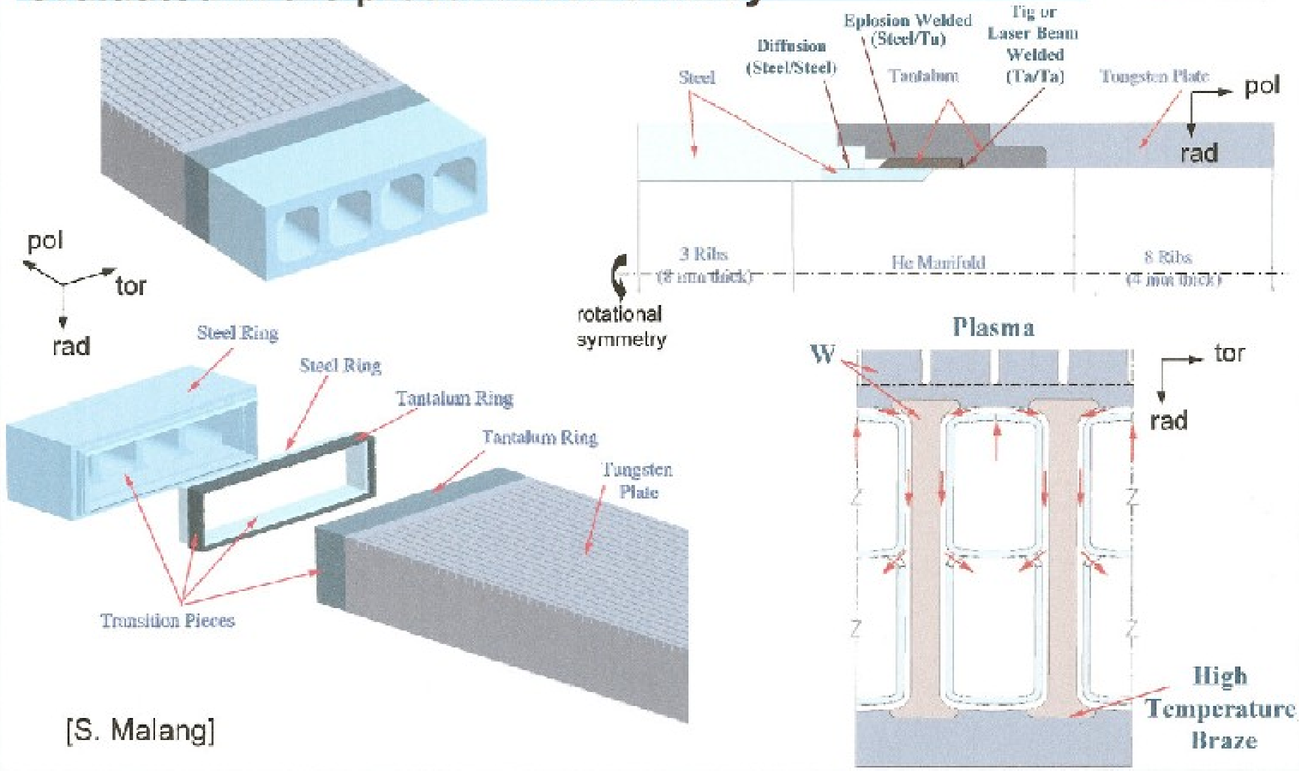
* He-cooled modular divertor with jet cooling



Advanced ARIES T-Tube Divertor



Outlook (2): „Modified plate divertor concept" to be evaluated in the present ARIES study



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Comparison of the different design options (plate, T-tube, small modules) for helium cooled divertor targets

a) For a heat flux of 10 MW/m^2 the temperature of divertor structure can be kept inside the anticipated temperature window for tungsten alloys (700 C to 1300 C).

b) Stresses and deformations caused by the temperature variation in the tungsten structure are smallest for the small modules and largest for the plate design.

c) The stresses in the plate design depend to a large degree on the kind of mechanical plate support. They assume a minimum value if the plate is allowed to bend and a maximum value if any bending is suppressed.

d) For a 1000 MW_{el} power plant the number of target elements is **500 plates** or **50,000 T-tubes** or **250,000 modules**